

MECHANICAL ASPECT OF CHIRALITY AND ITS BIOLOGICAL SIGNIFICANCE

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Abstract

Chirality is not just a structural artifact in biology but it may provide for a genuine biological advantage. This is due to the phenomenon of chiral interaction (CI) which is described here for mechanical-chiral devices. The main mechanical feature of chiral interaction is its mode of selecting one direction of rotation out of two possible and opposite ones. For example, a given chiral device such as a rotating water sprinkler, rotates in one direction. What does rotate in the opposite direction is the mirror of this given sprinkler. This mode of operation indicates space-time (PT) invariance which causes it to be also time-irreversible. This also causes a chiral device to become non-ergodic on microscopic level. This prevents certain chiral systems from readily reaching thermal equilibrium, and causes the system to act non-ergodically, which is crucial for living systems as well as for molecular evolution.

I. Introduction

The phenomenon of structural chirality of crystals and molecules has been recognized since the early 19th century when Arago¹ and Biot² did demonstrate the effect of optical activity in quartz crystals. Louis Pasteur³ was the first to observe chirality on a molecular level and specified it as “dissymmetry”. The term “Chirality” was first proposed by Kelvin⁴, who also defined this concept as a property of any object that cannot superimpose, or overlap, completely its mirror image. It is well known nowadays that most biological molecules consist only of one out of two possible enantiomers, e.g., left-handed (L) amino-acids or right-handed (D) sugars. This phenomenon leads to an interesting question concerning the origin of such a selection and there exist several speculations that try to solve this enigma. A considerably more constructive question to be asked is: “why are the molecules of life chiral?”, or “is there any biological advantage in their chiral nature when compared to achiral molecules?” And the answer to be given here is: “Yes”, and this is regardless of their being L or D. The source of such an advantage comes from a specific type of **interaction** that exists between various mechanical devices and different media such as flow of air or water and even light radiation. What is special about this interaction is the presence of chiral structure in these devices which makes their mode of operation quite different from other interactions which are based on achiral objects such as the Newtonian mass point. Such an interaction is to be labeled “chiral interaction” (CI) and it has already been described and treated in several

publications.^{5–7} It is interesting to note that this phenomenon of chirality is largely being overlooked in classical mechanics, and only a few physicists are aware of it.

II Chiral Interaction in Mechanical Devices

As mentioned above Chiral interaction is not limited to molecular structure only but there exist various mechanical chiral devices that function according to the same principle. The most spectacular example is the rotating windmill. When wind blows at the rotors of a mill it “knows” immediately in which direction to rotate, clock- or anti-clockwise. If the windmill, in particular its vanes, were symmetric with respect to their axis of rotation, the mill would not be able “to make up its mind” in which direction to rotate. The shape of the vanes that come in contact with the wind is designed to break the L-D symmetry in order to choose **one** specific sense of rotation out of **two** possible ones. In other words, the shape of the vanes where they come in contact with the wind, is **chiral**. Another simple mechanical chiral device is the rotating water sprinkler, or the wind propeller. The next example, shown in Fig. 1, is somewhat more sophisticated, and it depends on a different mode of chirality. This device is a simple variant of the Crookes’ radiometer. The active medium in this case is light radiation and the element of chirality consists of two different colors on both sides of the rotating blades, being black and silver, respectively. This is a special example of a physical rather than a geometric chirality. Physical chirality^{7,8} is presented by a chiral distribution of a physical property rather than of a chiral geometric shape.

Physical chirality differs from a geometric one in its capability of interacting with various media surrounding it. In the case of this special example of a variant of the ordinary Crookes' radiometer, the physical distribution of the black and silver colors on the blades represents a large difference in the light absorption coefficient of the blades. The silver side reflects back the light, whereas the black side absorbs the light and therefore becomes warmer in comparison to the silver one. This causes the air at the black side to become heated and as a result it expands and pushes back the black blade which ends up in rotating the device in **one** preferred direction out of **two** possible ones, that is, in the direction of the black side of the blade. The selection of the sense of rotation of the blades is made by the variance of colors on the blades and their interaction with light. The physical chirality⁷⁻⁸ here is represented by the distribution of the optical absorption coefficient on the blades and **not** by their geometric shape.

So far, all the examples presented here are of mechanical nature, i.e., the effect of chiral interaction (CI) results in a mechanical rotation in one preferred direction out of two possible ones around a given axis of the device. This is so because the source of the interaction, i.e. the medium, usually is external to the chiral device. In the case of an electric device which generates a static current flowing in one preferred direction out of two possible ones, the source of the interaction may be embedded within the device. This is the case, for instance, of an electric cell which consists of two different electrodes coming in contact with an electrolyte. It is obvious that in order

to reverse the direction of the current it is necessary to interchange the two electrodes with one another, but this does not necessarily require any chiral operation. This is so because the source of the current flow is internal, so that the structure of the device can be designed to be completely symmetric, as is the case of a cylindric battery. In the case of an electric thermocouple, the operation can still be regarded as CI since the source of the interaction, i.e. the temperature difference, is external to the device.

To summarize the main features of CI in mechanical-devices let us notice that in all these examples there exists a specific medium with which the chiral device is interacting and this always happens at an interface separating the device from the active medium. The physical chirality is **built** into this very interface. CI is a process by which energy is transferred from the active medium into the chiral device which causes a rotational motion, being usually of mechanical nature. The most significant aspect of the chiral interaction process is its mode of selecting only **one** direction of rotation out of **two** possible ones, which is to be attributed to the **chiral** nature of the device. The **mirror image** of the given chiral device, interacting with the same medium, does produce the same rotational motion in the **opposite** direction. This is to be regarded as a main feature of chiral interaction.

The effect of CI on a molecular level is less recognized in comparison to that of macro-chiral devices. The main reason for this is that CI occurs

mainly within the chiral system, or molecule, in the form of a small perturbation which is not easy to detect experimentally. Much more recognizable are the physical effects associated with molecular chiral structure, such as optical activity and related effects. These are to be regarded as “chiral scattering”, rather than CI, since the observable effect concerns the polarized light being scattered away from the chiral molecule rather than its effect on the molecule itself which is the chiral interaction⁷.

A physical model of chiral interaction (CI) in soluble proteins and amino-acids has already been developed and described in detail in several publications^{5-7,9-10}. The description here contains only a few main features of this model. The active medium in this model consists of random motion of ions throughout the solvent, being mostly regular water. The chiral element that interacts with these ions is an electric dipole moment that exists in the protein structure. This interaction causes the moving ion to be deflected away from its original track of motion, which creates a continuous perturbation along the α -helix of which the proteins consist, and this perturbation moves along the helix in **one** preferred direction out of **two** possible ones. This is an abbreviated description of the model of the CI that occurs in soluble proteins. A more detailed description appears in earlier publications.^{5-7,9-11} The perturbation resulting from this CI is of electric nature, rather than mechanical one. Another interesting aspect of this CI is that it happens at an interface separating the interior of the protein molecule

from the solvent and this is due to the globular structure of the soluble protein. It is well known that all soluble proteins become globular before they can function as enzymes¹².

As mentioned above chiral interaction is not easy to observe experimentally on a molecular level due to the smallness of this effect. Nevertheless, there exists a certain strong supporting evidence owing to an experiment performed by Careri et al.¹³. This experiment concerns the effect of dehydration on the protonic, or ionic, motion throughout the hydration layers surrounding soluble proteins. The amount of water around each protein is crucial for free protonic motion around the molecule. By dehydrating these water layers, a level is being reached when protonic motion becomes awkward and stops, and so does also, simultaneously, the enzymatic activity of the protein molecule. On re-hydrating the molecule, protonic motion becomes possible again and this, in turn, causes also the onset of enzymatic activity of the protein molecule. This experiment shows that free ionic motion around soluble protein molecules is crucial for their enzymatic activity.

III Physical Aspects and Biological Significance

The main objective of the present article is to draw several physical conclusions from the phenomenon of chiral interaction in macro-chiral devices which are quite different from the regular rules that exist in classical physics. The source of these differences arises from the presence of chirality as a major physical object instead of the Newtonian mass point that plays a basic

role in classical mechanics and is also of ideal spherical symmetry, that is, completely achiral. From these conclusions analogies can be drawn for the function of molecular chiral systems which may well be of considerable significance in molecular biology.

The first conclusion concerns the symmetry operation of time-reversibility that exists in many examples of classical physics. In the case of chiral devices time-reversibility does not exist. The windmill, for example, rotates about its axis in a given direction due to its chiral design. Upon reversing time, the rotational velocity changes its direction, so that it rotates in the opposite direction. This cannot happen mechanically, since there is no mechanism in a windmill that can rotate it backward. What is rotating in an opposite direction is the **mirror-image** of the given windmill but not the given windmill itself. The meaning of this mode of symmetry operation is that a windmill is time-irreversible, but it obeys space-time invariance. Let us now express the space-time inversion by P and T , respectively: then a windmill does obey the PT-invariance transformation. The same is true for all the examples given here of macro-chiral devices. The same is also true for the protein molecule example. This rule of PT-invariance (or CPT invariance) is recognized in physics due to the presence of a spin in quantum mechanics, but is absent in classical physics because the concept of structural chirality in physics it is largely ignored. This concept appears much more in chemistry due to the presence of many chiral molecules in organic compounds, but chirality is mostly regarded and treated in chemistry in terms of shape, rather

than in its physical properties and contents. For this reason the concept of CI has so far been largely overlooked in researches concerning chirality.

These space-time symmetry operations for chiral devices contain also a certain aspect of practicality. This is in contrast to their presence in the domain of elementary particles in physics. From this view point any time-reversible process is almost completely useless from any aspect of practicality. For instance, any machine operation that produces a certain function or object, or any information transfer process are completely time-irreversible. These include also biomolecular functions such as enzymatic activity and other processes which are totally time-irreversible. For such reasons of practicality the function of chiral devices or molecules is of special significance in comparison to the time reversible phenomenon that appears in many physical operations that involve the presence of the Newtonian mass point.

The next consideration involves the mode of selection where only **one** direction of rotation is excited by CI, whereas the opposite direction remains largely inactive. Judging it from a thermodynamical aspect, what is happening here is that only one half of the energy that can be activated by the device is excited by CI whereas the other half remains inactive. On a molecular level this means that only one half of the energy states of the system are populated by CI become active, whereas the other half remains empty. In other words the system does not readily reach thermal equilibrium. This conclusion is of very substantial and significant meaning for living systems

because reaching thermal equilibrium means death.

Another way to look at this effect is from the view-point of ergodicity. This concept was introduced by Boltzmann about a century ago and it regards the mode of approaching thermal equilibrium of a single particle. This is done in a process of time average instead of an ensemble statistical average. In view of this, the average velocity of such a particle in any given direction approaches zero as a function of time. This is not the case if, for instance, the average angular velocity of a windmill is regarded as a function of time. This is, actually, true for any effect of CI when averaged as a function of time. The selection of one direction of motion out of two possible ones, which is typical of CI, makes its mode of motion to become a non-ergodic entity, which again causes it to avoid thermal equilibrium. This property of CI on a microscopic level is, apparently, one of the most crucial advantages that chirality, or CI, does contribute to molecular biology. It does postpone thermal equilibrium, or death, for a considerable length of time, so that the biological function of these molecules can go on and not be affected by approaching thermal equilibrium.

In this context it is interesting to mention also Schrödinger who became interested in the phenomenon of life and wrote a book “What is Life?” in 1944¹⁴. His main conclusion in this book was: “It feeds on negative entropy”, and this is exactly what CI is performing in its mode of selecting only one

direction of motion. It is thus reducing the entropy of the system.

In relation to the phenomenon of non-ergodicity it is also important to mention its relevance to the process of evolution, which is crucial in biology. It is reasonable to deduce that systems that reach readily thermal equilibrium never undergo the process of evolution and remain basically unchanged forever. Non-ergodic molecular systems have a better chance to undergo evolutionary changes.

IV Discussion and Conclusions

Another aspect of CI regards the nature of this effect, as well as the amount of energy that is involved in such a process. In discussing this case it is not relevant to consider macro-chiral devices and our main concern is CI of biomolecular systems. Unfortunately, our knowledge, at present, of this effect is very limited and this is mainly because of the small amount of energy involved in this effect, being, in fact, subthermal in size^{5-6,10}, which is quite difficult to observe experimentally. This may evoke criticism as to its possible significance. Such a criticism is rather common among scientists who tend to attribute significance to energy according to its size. What may be much more significant than the amount of energy involved in a process, is its quality, or degree of sophistication. This is particularly so in complex systems such as certain biomolecules, proteins for example. The feature of time-irreversibility of CI does contribute a degree of sophistication. In addition to this there exist quite a few examples of highly sophisticated modes

of energy which require rather minute quantities of energy. For instance, an information transfer process requires a high degree of sophistication in wave modulation and its size of energy is relatively small. In comparison, boiling a kettle of water requires much more energy, but what is its degree of sophistication? Another example is the small amount of energy required to switch on and off a much larger source of energy. This example can be regarded as a mode of control mechanism energy which may also be the significance of CI in biology. Another, rather cruel example, concerns the magnitude of energy change that occurs over a short time interval during which a creature ceases to live. The change in energy is quite small but its significance is impressive. In these examples and many others, the amount of energy involved in their performance is of little interest, but their main effect is in their degree of sophistication.

It is too early now to attempt to specify any definite mode of sophisticated performance of CI on a biomolecular level. Such effects have to be studied further in order to become better understood. The experiment of Careri et al.¹³ provides for a supporting evidence for the significance of CI in the enzymatic activity of proteins. It is quite reasonable to assume that in biology, or in any living substance, the phenomenon of existence of such modes of highly sophisticated and low energy signals may have an important function in its life process.

In conclusion, let us mention again the significance and importance of the phenomenon of chirality in biology, in particular the features of chiral interaction (CI) that differ largely from those of classical physics that do not contain chiral structure in their interactions. These include the PT-invariance of chiral interaction, which causes it to be time-irreversible. The selectivity nature of CI by preferring one mode of motion out of two possible ones, enables CI to become non-ergodic, which is a crucial element in life processes and biological evolution.

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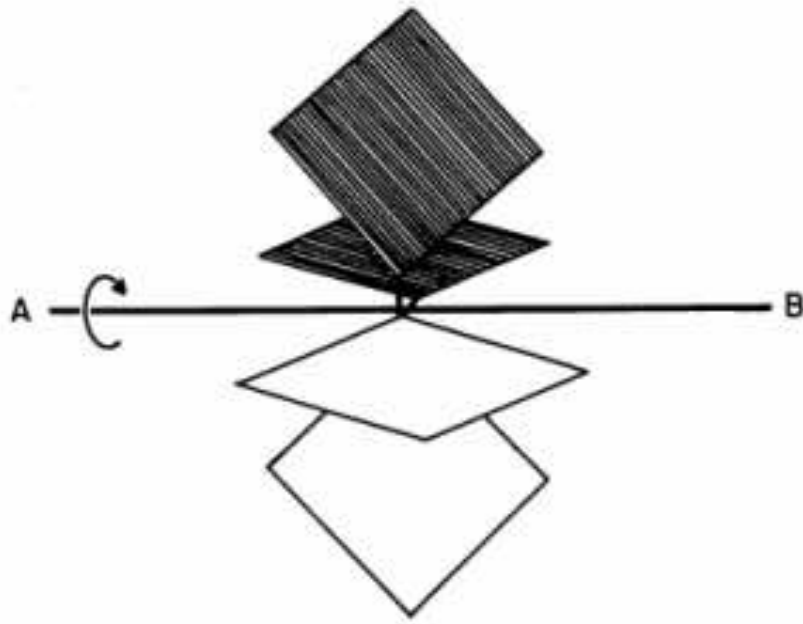


Figure 1: A variant of Crookes' radiometer is an example of chiral interaction (CI). The asymmetry in the optical absorption coefficient between the black and the silver blades generates a temperature difference between them when light is shining at the device. This expands the air close to the black blade which, in turn, pushes it around the axis AB in the preferred direction towards the black vane. This is an example of physical rather than of a geometric chirality